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RELATIONSHIP BETWEEN LINGUISTIC UNITS AND MOTOR COMMANDS.

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ASSUMING THAT SPEECH IS THE RESULT OF A NUMBER OF DISCRETE NEUROMUSCULAR EVENTS AND THAT THE BRAIN CAN STORE ONLY A LIMITED NUMBER OF MOTOR COMMANDS WITH WHICH TO CONTROL THESE EVENTS, THE RESEARCH REPORTED IN THIS PAPER WAS DIRECTED TO A DETERMINATION OF THE SIZE AND NATURE OF THE STORED ITEMS AND AN EXPLANATION OF HOW SPEAKERS ENCODE A SEQUENCE OF THESE DISCRETE LINGUISTIC UNITS INTO A CONTINUOUSLY CHANGING SIGNAL. THE TECHNIQUE OF ELECTROMYOGRAPHY WAS USED TO STUDY THE ACTIONS OF SOME OF THE MUSCLES IN THE MOUTH IN ARTICULATING "B,P,D" COMBINED WITH 12 AMERICAN ENGLISH VOWELS. RESULTS SHOWED THAT NO ONE-TO-ONE CORRESPONDENCE EXISTS BETWEEN PHONEMES AND MOTOR COMMANDS. TWO MOTOR COMMANDS DIRECTED SIMULTANEOUSLY TO THE SAME MUSCLE RESULT IN MUSCULAR ACTIVITY EQUAL TO THAT NECESSARY FOR THE PRODUCTION OF THE SOUND REQUIRING THE GREATEST TENSION. IF MOTOR COMMANDS CALL FOR A SEQUENCE OF GESTURES AND THE FIRST GESTURE REQUIRES MORE MUSCLE ACTION THAN THE SECOND, THE ACTION FOR THE SECOND GESTURE IS DECREASED. HOWEVER, WHEN THE SECOND GESTURE REQUIRES A GREATER OR EQUAL AMOUNT OF ACTIVITY, A MORE OR LESS SIMPLE CONCATENATION OF GESTURES RESULTS. ALTERNATIVE HYPOTHESES ARE DISCUSSED TO ACCOUNT FOR THESE DATA AND ARE SUGGESTED AS TOPICS FOR FURTHER EXPERIMENTS. THIS PAPER WAS PRESENTED AT A MEETING OF THE ACOUSTICAL SOC. OF AMER., BOSTON, JUNE 1, 1966. (JD)

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Relationship between Linguistic Units and Motor Commands

Before any useful model of speech performance can be constructed further research is required to provide more detailed knowledge than is now available about the encoding and decoding processes which occur. It seems logical, however, to start with the assumption that the semi continuous acoustic signal that we call speech is the result of a number of discrete neuromuscular events. We cannot store in our brain motor commands for every utterance that we may wish to say, owing to the brain's finite storage capacity. Speech then is produced by the rearrangement of a limited number of stored items. One of the problems to be resolved is the determination of the size and nature of the stored items, and to exnlain how speakers encode a sequence of these discrete linguistic units into a continuously changing signal. We are assuming that at some previous level of brain activity some grammatical and semantic unit of a sentence has been encoded into a series of discrete segments, which must be further encoded into signals xx to activate the muscles in such a way that speech sounds are produced.

We have here a 'black box' situation, but one in which the only data we can examine is the ouput, i.e. the activity of the muscles, the articulatory gestures, and finally the acoustic signal. We must make certain assumptions about the input into the motor command mechanism, and about the transformations which take place. We are unable to look into the speaker's brain, and even if we did so, it is unlikely that this would reveal the encoding mechanism.

Can we assume the input to be phonemes, such that there is a one-to-one mapping of phonemes or phon · · features onto individual motor commands? Our own investigations suggest that this is not the case.

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Using the technique of electromyography, a study was made of the actions of the orbicularis oris muscle in the articulation of CVC monosyllables, in which the Consonants were /b,d,p/ combined with 12 American English vowels. This sphincter muscle which surrounds the mouth opening has as its functions the closing and protrusion of the lips. It is therefore activated in a bilabial closure and in the production of rounded vowels. The action potentials, recorded by an electrode placed over this muscle, of twenty tokens of each utterance were averaged using a LINC general purpose computer.

We shall summarize some of the results of the study which are relevant to the encoding process.

In the slides to be presented, the horizontal axis represents ~~three~~ 1.1 seconds of time, and the vertical axis the recorded voltage in microvolts.

1. No one-to-one correspondence exists between phonemes and motor commands. Slide 1.

This demonstrates that the muscle activity which produces an initial /b/ is of greater amplitude and duration than that producing a final /b/.

This is further illustrated by Slide 2.

Here one sees the superimposition of averaged EMG traces in initial and final /b/ utterances. It is evident that there is no invariant motor command for the phoneme /b/ independent of context.

2. The gesture responsible for an initial bilabial closure was unaffected by the vowel which followed. The variability between all the initial /b/ utterances, of /b/ followed by different vowels, is relatively no greater than the difference between an initial /b/ of the same utterance recorded on two separate occasions.

Slide 3.

This slide shows the variation of orbicularis action which

occurs xxxxx between /bIb/ utterances, and those between /bub/ and /bIb/.

It is evident that two motor commands, if this is what occurs, directed to the same muscle do not result in a simple addition of the number of motor units contracting. When the motor commands call for the gestures to occur simultaneously, the resultant muscular activity is equal to that necessary for the production of the sound requiring the greatest tension.

3. When motor commands call for a sequence of gestures, if the first gesture requires more muscle action than the subsequent gesture, the action for the second gesture is decreased.

Slide 4

Viewing the superimposition of /bud/ and /dud/ EMG traces, and there is a /bod/ with /dod/ traces, it is evident that a decrease of the muscle action associated with the vowel when the vowel follows a consonant in which there is greater expenditure of effort. Physiologically this is explained by a simple inertial effect, that is, it is harder to start an object moving than it is to keep it moving once it is started.

4. Finally, it was found that when motor commands call for a sequence of gestures, where xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx the second gesture requires a greater or equal amount of activity, a more or less simple concatenation of gestures results.

Slide 5

Here you see the superimposition of utterances in which the vowel is /u/ and the final consonants /b/ and /d/. Little difference if any results from a final /b/ as opposed to final /d/.

Alternative hypotheses are suggested to account for these data. We can assume that the input to the neuromotor mechanism is not a sequence of phonemic segments but of phonetic segments, allophones. Such a proposal assumes that there is stored in the brain a separate command for every possible allophone. It is logical to assume this to be the case for what Ladefoged has called extrinsic allophones, those not resulting from coarticulation factors or overlapping commands, but which require a different set of motor commands, such as is illustrated by the differences between initial and final /b/. But ~~fmx~~ intrinsic allophones which are the result of immediate phonetic context may be processed and transmitted directly as signals to the muscles. Thus, the decrease in the muscular contractions for an /u/ preceded by a /b/ would be the result of the previous muscular state.

How the intrinsic allophones are processed, that is, how the neighboring sounds influence antecedent or subsequent sounds ~~mmmx~~ also suggest alternative explanations.

One can assume that ~~x~~ by a feedback mechanism the output ~~xmxmmxixmmmd~~ -- muscle state -- is monitored, which information is sent back to the motor command encoding devise to ~~x~~ change the/subsequent commands. ~~mfxixhm~~ ~~mmmmmqmmnx~~ However, the rapidity of the articulation process, coupled with the delay time necessary for the proprioceptive feedback would not permit feedback from the peripheral organs to modify the signals from the nervous system in time. However, in certain neural systems, the signals themselves may be monitored, that is, the nervous system can look at the command rather than at the output and change a subsequent command in keeping with the requirements to achieve the new gesture.

There is an alternative explanation; namely that the linguistic unit corresponding to individual sets of motor commands is not of the size of a phoneme or allophone, but rather that of a syllable, or some combination of phonemic segments. Much supporting evidence for this

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position has been advanced. For example, in a CV syllable, in which the vowel is marked by a rounding feature, the protrusion occurs simultaneously with the articulation of the consonant, and in some case even before.

The suggestion that the units for the articulatory program are syllable-type units is supported further by Kozhevnikov and Chistovich in Leningrad, whose provide support for the idea that syllable commands are rhythmically organized by a separate rhythm generator in the nervous system, distinct from the articulatory generator.

If this is the case, either one must conclude that a many-to-one encoding process occurs -- allophones to syllables -- which new units are mapped onto motor commands. Alternatively, the message may be originally encoded into units larger than phonemic segments, i.e. syllables. It is conceivable that individual sets of motor commands corresponding to syllables are stored. It ż seems more plausible that the syllable units are complex units encoded in phonemic or allophonic segments and these sub-syllabic units are mapped onto motor commands by the feedback mechanism suggested. This would require less storage capacity and would explain the errors which occur in speaking in which parts of syllables persevere or are anticipated.

While the present state of knowledge excludes any definitive answers to the questions raised, the alternative suggestions do account for the data. New data, and the discovery of new relationships should provide the basix for ŋŋŋŋ ż possibly better explanations. We therefore view our surgestions as working hypotheses on which to base further experiments.

Acoustical Society of America, June 1, 1966, Boston, Massachusetts

Relationship between Linguistic Units and Motor Commands

Victoria A. Fromkin, U.C.L.A.

I. Summary of some of the results of an Electromyographic study of orbicularis oris muscle. Utterances were CVC monosyllables: C = /b,d/, V = /u,ʊ,i ,/

1. In utterances in which both C_1 and C_2 = /d/, e.g. /d_d/, no muscle activity was recorded when V = /i/; muscle action potentials were recorded when V = /u/ and /ʊ/.

2. In all utterances in which /b/ occurred, muscle activity was recorded; for initial /b/ the action potentials occurred prior to the onset of the audio signal, for final /b/ the action potentials (AP) occurred after the onset of the audio signal.

3. When /b/ occurred initially, the muscle action was greater in amplitude and duration than when /b/ occurred finally.

4. The muscle action associated with an initial and final /b/ was unaffected by the quality of the vowel which preceded or followed it.

5. The action potentials produced in the articulation of /dud/ i.e. of the vowel /u/ , started prior to the onset of audio and extended after the onset of audio. There was less muscle action after the onset of audio when /u/ was preceded by /b/ than when /u/ was preceded by /d/.

6. The muscle activity associated with /u/ and /ʊ/ was independent of the consonant which followed, i.e. when followed by a /b/ which also showed action potentials there was no difference than when followed by a /d/ which showed no muscle action.

7. The muscle action potentials produced in the utterance /bʊd/ were relatively indistinguishable from that for /bid/.

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